Bandwidth Enhancement of Small-Size LTE/WWAN Coupled-fed Loop Antenna with Distributed Parallel Resonant Circuit

Shu-Chuan Chen[1], Jia-Yi Sze[1*], and Yi-Chun Chu[1]

[1] *Department of Electrical and Electronic Engineering, Chung Cheng Institute of Technology, National Defense University*

ABSTRACT

A small-size LTE/WWAN coupled-fed loop antenna with a rotated U-shaped strip for laptop-computer applications is presented. The coupled-fed loop antenna formed by a feeding strip and a coupled shorted strip can support two operating bands, which cover the desired frequency bands. The compactness of the antenna is achieved by embedding a rotated U-shaped strip into the coupled-fed loop, and a distributed parallel resonant circuit is employed in the design to expand the bandwidths of the lower and higher bands. The proposed antenna is a uniplanar structure and is easy to be fabricated on a thin FR4 substrate with an area of only 10 × 50 mm^2. The antenna efficiencies are about 51-64% and 62-81%, respectively, over the lower and upper bands.

Keywords: LTE/WWAN antennas, multi-wideband antennas, distributed parallel resonant circuit

以分佈式並聯諧振電路增強小型 LTE/WWAN 耦合饋入迴圈天線操作頻寬之設計

陳淑娟[1]　施家頤[1*]　朱繹中[1]

[1]國防大學理工學院電機電子工程系

摘　　要

本文提出一個可應用於膝上型電腦的小型 LTE/WWAN 耦合饋入迴圈天線設計。僅由一個饋入金屬帶與一個耦合短路金屬帶組成的耦合饋入迴圈天線已能提供兩個獨立分離的操作頻帶，但無法涵蓋想要的 LTE/WWAN 設計頻帶。為使天線能以縮小型的尺寸改善以上缺點，大幅擴增操作頻寬，藉由在原有的耦合饋入迴圈中植入一個倒 U 形金屬帶以形成一個分佈式的並聯諧振電路，便能擴增原有的兩獨立分離的窄操作頻帶，以涵蓋想要的設計頻帶。本文所提出的天線設計具有單面印刷的金屬結構、易於製作於一薄基板上以及僅有 10 × 50 mm^2 的小面積尺寸。除此之外，位於設計頻帶的低頻帶與高頻帶的天線輻射效率分別達到 51-64%與 62-81%範圍。

關鍵詞：LTE/WWAN 天線，多寬頻帶天線，分佈式並聯諧振電路

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Ⅰ. INTRODUCTION

In recent years, laptop computers have become thinner and lighter, while their good performance remains. Such a development has greatly alleviated the need of installing communication antennas in a room. In the meantime, laptop computer antennas are required to cover the GSM 850/900/1800/1900/UMTS and LTE 700/2300/2500 operating bands to support the Long Term Evolution (LTE) and Wireless Wide Area Network (WWAN) for 2G/3G/4G communications. The requirement of large lower-band bandwidth is challenging the design of an internal antenna embedded in the laptop computer than those in the tablet computer and mobile handset. This is because the size of the system ground plane of laptop computer is much larger than those of the tablet computer and mobile handset [1-4], thus makes the chassis mode of the laptop computer's system ground plane not being easily excited for achieving a wider lower band by the embedded internal antenna.

To provide two wide operating bands for the LTE/WWAN operation, some internal antennas reported in [5-10] were designed to employ additional slots or metal strips to generate additional resonant modes, to enhance the bandwidth of the lower band. However, such designs are not helpful to the miniaturization of antennas. Other antennas reported in [11-17] used a band-stop lumped-element matching circuit or a distributed parallel resonant circuit (PRC) to enhance the bandwidth. Although a lumped-element matching circuit can enhance the bandwidth of the antenna's lower band, several drawbacks are incurred. For example, the occupied volume of the antenna may increase, and lumped elements may decrease the radiation efficiency and increase the fabrication cost of the antenna. In contrast, the literature has shown that PRC techniques can effectively enhance the bandwidth and retain the small size of the antenna. In particular, parallel PRCs of planar configuration are usually printed on one or both sides of a thin dielectric substrate, suitable for slim tablet or laptop computer applications. The required dimension along the top edge of the display ground plane is at least 40 mm [12], in which the antenna shows a uniplanar structure occupying an area of 40×12 mm^2 for an WWAN operation. However, it is still very difficult to support LTE/WWAN eight-band operation by a simple structure built in such a small area. In order to cover the LTE/WWAN operating band with a uniplanar printed antenna, new bandwidth-enhancement techniques are proposed.

In this article, we present a promising design of a laptop computer's internal antenna using the combined techniques which integrate a coupling feed and a distributed PRC to cover the LTE/WWAN operation (698–960 and 1710–2690 MHz) with a reduced antenna size design. The antenna comprises a feeding strip, a coupled shorted strip, and a rotated U-shaped strip, all are printed on the same FR4 substrate. The feeding strip together with the coupled shorted strip form a coupled-fed loop antenna, and the rotated U-shaped strip configured with the coupled shorted strip form a distributed PRC to achieve a compact antenna structure with a wide lower band. The distributed PRC does not need extra area of the antenna and generates a parallel resonance at about 1300 MHz, which results in an extra resonance and leads to a new resonant mode excited at about 950 MHz. This resonant mode greatly enhances the bandwidth of the antenna's lower band and it together with the quarter-wavelength mode of the coupled-fed loop antenna cover the desired LTE700/GSM850/900 operation. The antenna's upper band is formed by the higher order resonant modes of the coupled-fed loop antenna and an additional resonant mode created by the rotated U-shaped strip. The upper band shows a large enough bandwidth to cover the desired GSM1800/1900/UMTS/ LTE2300/2500 operation.

Owing to the proposed techniques using a coupled-fed loop and a distributed PRC, the antenna requires a dimension of only 50 mm in length along the top edge of the display ground of the laptop computer. Upon the proposed techniques, the antenna's metal pattern with an area of 10×50 mm^2 can be printed on one side of a small-size planar FR4 substrate only. In this article, details of the proposed antenna are described. Effects of the coupling feed and the distributed PRC for bandwidth enhancement of the proposed antenna are discussed.

Ⅱ. PROPOSED ANTENNA

Figure 1 shows the structure of the

proposed antenna. The antenna is mounted along the top edge of the display ground. The dimensions of the display and keyboard grounds are selected to be 260×200 mm^2, which are reasonable dimensions for the laptop computer with a 13-inch display panel. The proposed antenna is formed by a coupled-fed loop antenna and a rotated U-shaped strip, all are printed on a 0.4-mm-thick FR4 substrate of size 10×50 mm^2. The rotated U-shaped strip is connected to the place near the input port of the coupled-fed loop antenna. The coupled-fed loop antenna composed of a feeding strip and a coupled shorted strip can generate one and two resonant modes in the lower and upper bands, respectively. However, the lower and upper bandwidths are too narrow to cover the desired frequency bands for the LTE/WWAN operation.

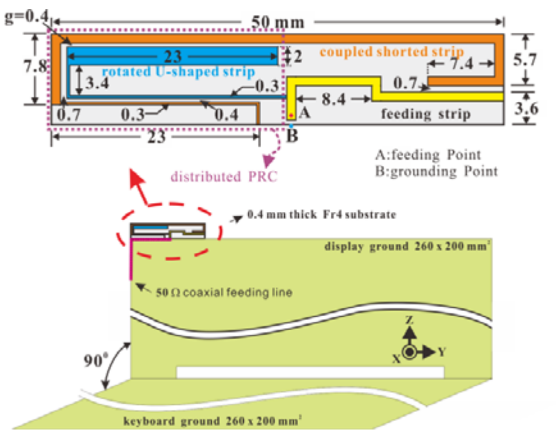

Fig. 1 Geometry of proposed antenna for laptop-computer application.

The rotated U-shaped strip is encircled by the coupled shorted strip with a coupling portion to form a distributed PRC. The coupled shorted strip provides a distributed inductance while the coupling portion formed by the coupled shorted strip and the rotated U-shaped strip provides a distributed capacitance. The distributed PRC leads to a parallel resonance generated at about 1300 MHz, which results in a new resonance (zero input reactance) occurring nearby and leads to a new resonant mode excited at about 950 MHz. This new resonant mode combining with the quarter-wavelength mode of the coupled-fed loop antenna cover the desired LTE700/GSM850/900 operation (698–960 MHz), which greatly enhances the bandwidth of the antenna's lower band. In addition, the rotated U-shaped strip can generate a higher-order mode at about 2610 MHz. This mode together with those created by the feeding strip and the coupled shorted strip cover the GSM1800/1900/UMTS/LTE2300/2500 operation. To feed the antenna, a 50-Ω mini coaxial line is used, whose central conductor and outer grounding sheath is connected to point A in the feeding strip and point B in the antenna ground, respectively. The proposed design was verified by measurements. A photo of the fabricated prototype antenna is shown in the Figure 2.

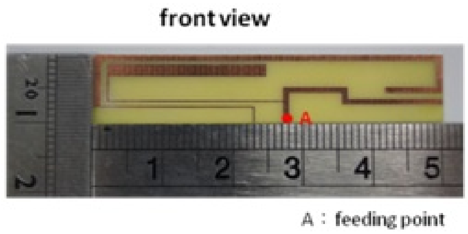

Fig. 2. Photos of the fabricated antenna.

Ⅲ. RESULTS AND DISCUSSION

Figure 3 shows the measured and simulated return loss of the proposed antenna. The simulated results are obtained using the three-dimensional (3D) full-wave electromagnetic field simulator [18]. Agreement between the measurement and simulation is obtained, and some slight frequency differences in the resonant modes (for example, the one at about 2.6 GHz) may be owing to the deviation of the substrate permittivity.

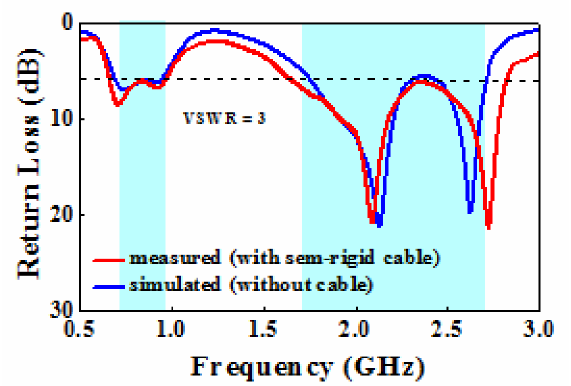

Fig. 3. Measured and simulated return loss of the proposed antenna.

Figure 4 shows the simulated return loss and input impedance for the proposed antenna, the case with the feeding strip only (denoted by Type 1), and the case with the feeding strip and coupled shorted strip (denoted by Type 2). For the case of the feeding strip only (i.e., Type 1), a resonant mode at about 2100 MHz is generated (although the impedance matching is not good). When the coupled shorted strip is added to Type 1 forming the Type 2 design, two additional resonant modes are generated, with one mode at about 780 MHz and the other at about 2250 MHz. The mode at about 2250 MHz also combining with the one created by the feeding strip widen the bandwidth of the antenna's upper band. Then, by adding to Type 2 circuit with the rotated U-shaped strip forms the proposed antenna. It is clearly shown in Type 2 design that a wideband resonant mode at about 950 MHz is generated, makes the antenna capable of covering the desired 698–960 MHz band.

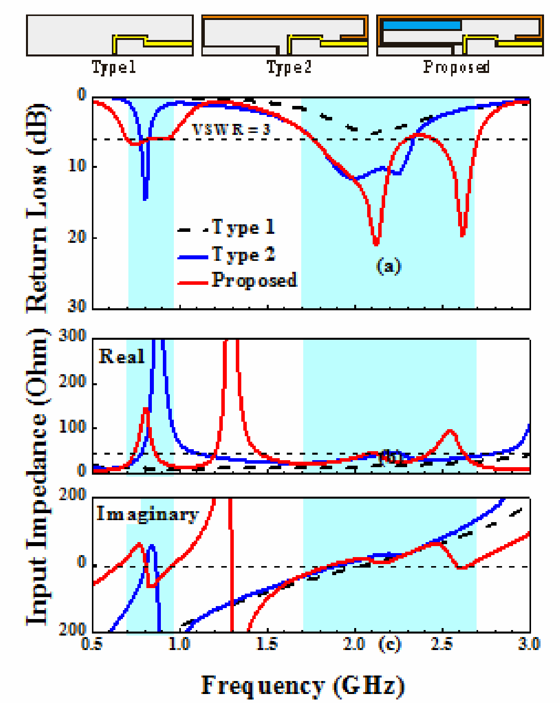

Fig. 4. Simulated S parameters for the proposed WLAN MIMO antenna array, the Type1 design, and the Type2 design.

This wideband behavior can be explained from the comparison of the simulated input impedance for the proposed antenna and the case without the rotated U-shaped strip (Type 2) in Figures 4(b) and 4(c). In these figures, it is clearly observed that a parallel resonance is generated at about 1300 MHz and a new resonance occurs at about 980 MHz (where the imaginary part of the input impedance is zero) which leads to the wideband resonant mode excited at about 950 MHz (where the return-loss curve dips), as shown in Figure 4(a). In addition, the rotated U-shaped strip can generate a higher-order mode at about 2610 MHz. This mode also together with the ones created by the feeding strip and coupled shorted strip cover the GSM1800/1900/UMTS/ LTE2300/2500 operation. Two wide operating bands covering the desired lower and upper bands for the eight-band LTE/WWAN operation (the shaded regions in Figure 3) are obtained. The impedance matching for frequencies over the desired lower and upper bands is better than 3:1 VSWR or 6-dB return loss.

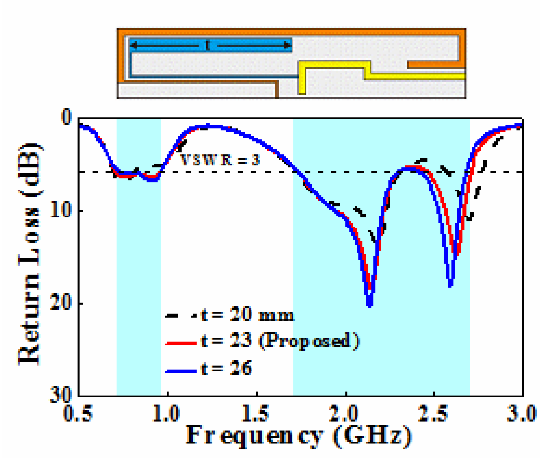

Fig. 5. Simulated return loss as a function of the length t of the coupling section of the rotated U-shaped strip.

Effects of the coupling section between the rotated U-shaped strip and the coupled shorted strip are analyzed in Figures 5 and 6. The simulated return loss is presented in Figure 5 for three different values of the length t (indicated in the inset of this figure), the length of the upper horizontal arm of the rotated U-shaped strip. Results show that the second parallel resonance can be controlled by adjusting the length t, because it can lead to some variations in both the distributed inductance and capacitance in the distributed PRC. With a properly selected length t, good excitation of the second resonant mode in the lower band can be obtained. It can also improve the impedance matching of the first resonant mode in the lower band. Another major effect is seen in the resonant mode at about 2550 MHz. With a length of 23 mm, this resonant mode, a higher-order mode contributed by the rotated U-shaped strip, is excited in the desired upper band for the antenna. This behavior occurs in that the coupling section also accounts for a part of the resonant length of the coupled-fed loop antenna, especially at higher frequencies, and hence it will cause relatively large effects on the resonant modes at higher frequencies.

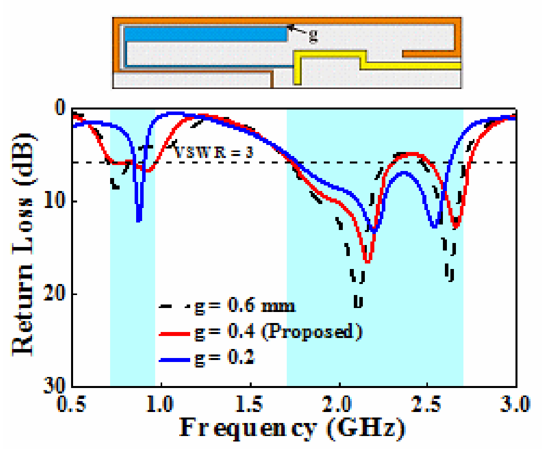

Fig. 6. Simulated return loss as a function of the width g of the coupling gap.

Results of the simulated return loss for the width g of the coupling gap varied from 0.2 to 0.6 mm are presented in Figure 6. In this case, large effects on the impedance matching of the resonant modes in both the lower and upper bands are seen. This indicates that the selection of a proper coupling-gap width is important in the proposed antenna to achieve good excitation of the quarter-wavelength and higher order resonant modes of the proposed coupled-fed loop antenna. A proper width of 0.4 mm for the coupling gap is preferred in the proposed antenna.

Effects of the length of the feeding strip on the formation of the antenna's higher band are also studied. Fig. 7 shows the simulated return loss for the length s varied from 8.5 to 11.5 mm. In this case, large effects on the impedance matching of the resonant modes in upper band are seen. This indicates that the selection of a proper feeding strip length is important in the proposed antenna to achieve good excitation of the higher order resonant modes of the proposed coupled-fed loop antenna with distributed parallel resonant circuit. A proper width of 13.5 mm for the feeding strip is preferred in the proposed antenna.

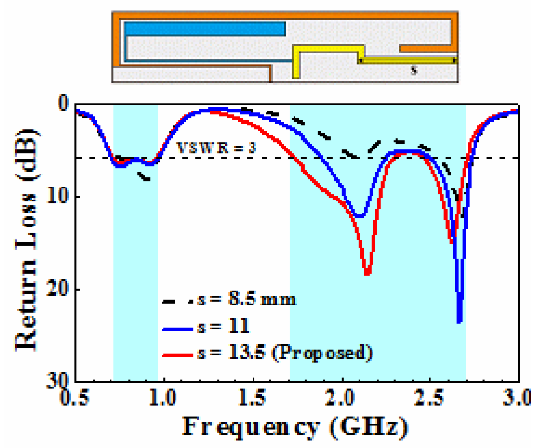

Fig. 7. Simulated return loss as a function of the length s of the feeding strip.

The radiation characteristics of the proposed antenna are also studied. Figure 8 shows the comparison of the simulated and measured radiation patterns at 740, 900, 2100 and 2200 MHz for the proposed antenna. Good agreement between the measured and simulated results is obtained. At each frequency, the radiation patterns in three principal planes are shown. Comparable E_θ and E_ϕ components are seen in the measured radiation patterns. Also, in the azimuthal plane (x-y plane), it is expected that the total power (E_θ and E_ϕ together) shows no nulls in all the ϕ angles. These radiation characteristics can lead to no communication nulls in practical application.

Figure 9 shows the simulated and measured radiation efficiency and antenna gain of the proposed antenna. Good agreement between the measured and simulated results is obtained. The measured results show that the radiation efficiency is about 51-64% and 62-81% for the lower and upper bands, respectively. The measured antenna gain varies within the range of 0.8-2.2 dBi for the lower band and 1.8-4.2 dBi within the upper band. The measured radiation efficiency and antenna gain are acceptable for practical applications.

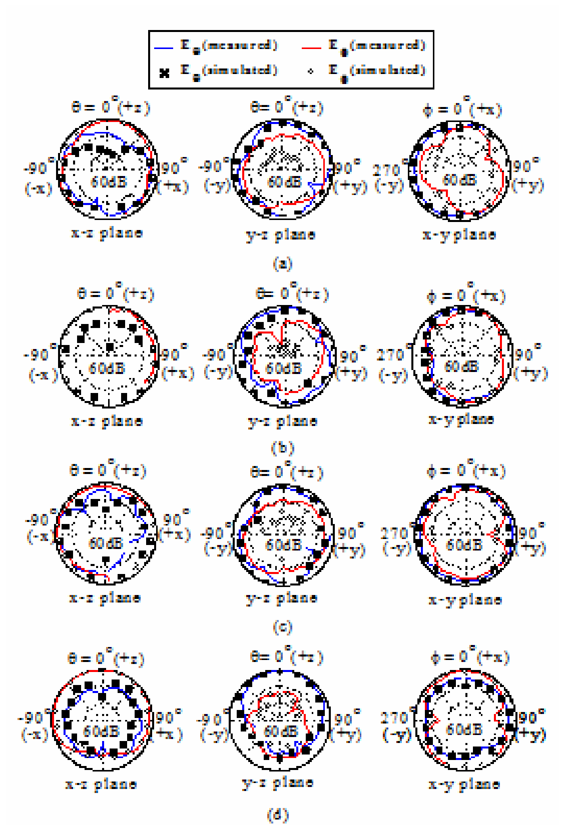

Fig. 8. Measured and simulated radiation patterns of the proposed antenna: (a) f = 740 MHz, (b) f = 900 MHz, (c) f = 2100 MHz, and (d) f = 2610 MHz.

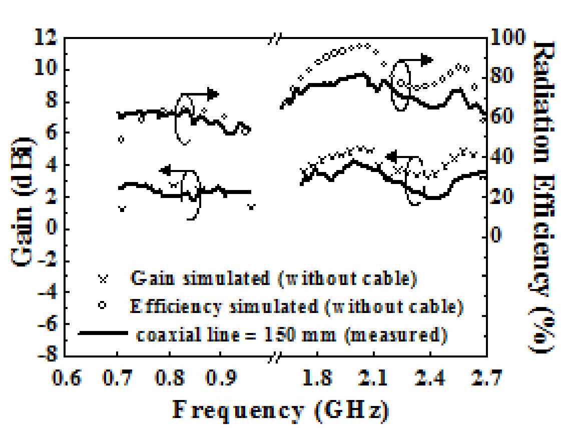

Fig. 9. Simulated and measured radiation efficiency and antenna gain of the proposed antenna.

IV. CONCLUSION

A promising small-size internal antenna of a laptop computer with a volume of 10×50×0.4 mm^3 for the eight-band LTE/WWAN operation has been proposed and studied. With a simple structure formed by a coupled-fed loop antenna and a rotated U-shaped strip, the proposed antenna can be easily implemented by a low cost PCB technology on a thin FR4 substrate. The techniques in achieving small circuit size, and wideband operation for the proposed antenna have been discussed in detail. The proposed antenna has also been fabricated and tested. Good radiation characteristics for practical applications have been observed. With the obtained results, the proposed antenna should be promising for practical laptop-computer applications.

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